- The pepper and water model is very small and not to scale. The Solar System is considerably larger!

15. Understanding the swirling cloud model. Explain to students that the model they have just worked with represents how scientists think the Solar System may have formed. Point out that, even with its inaccuracies, the model is useful for easily visualizing how a disordered system might have become a structured and ordered one. Post the following key concept on the classroom concept wall:

The Solar System formed from gas and dust that gravity drew together into a whirling system.

Session 3.10: Human-Powered Orrery

Overview

An orrery is a mechanical model of the Solar System that illustrates the relative motions and positions of bodies in the Solar System. The name comes from Charles Boyle, the 4th Earl of Orrery, for whom one of these models was made. **[RHP 3.10A & RHP 3.10B]**

In this session, the class works together to create a human-powered orrery to model the movements of the four inner planets. Students assist in setting up this moving model of the Solar System and take turns playing the roles of Mercury, Venus, Earth and Mars. As the class observes the orrery in motion, they form conclusions about the orbital periods of the inner planets. Afterwards, the class predicts the orbital periods of the outer planets using the mapped scale model transparency from Session 3.9.

During this session, the key concepts that will be added to the classroom concept wall are:

- ***Planets closer to the Sun have smaller orbits and move more quickly than planets farther from the Sun.***

- ***Objects in the Solar System are in regular and predictable motion.***

- ***As seen from Earth, the positions of the planets and the Sun are always changing.***

3.10: Human-Powered Orrery	Estimated Time
Setting Up and Running the Orrery	35 minutes
Reflecting on Planetary Motion	10 minutes
Total	**45 minutes**

What You Need for Session 3.10

For the class

- ❏ a 2.5 meter piece of thin rope or string (made out of a material that is not stretchy)

- ❑ several rolls of masking tape or blue painter's tape OR chalk
- ❑ overhead transparency of the map with outer planet orbits drawn in (from Session 3.9)
- ❑ overhead projector
- ❑ prepared key concept sentence strips
- ❑ Space Science Sequence CD-ROM (optional) **[RHP 3.10C]**
- ❑ computer connected to either a projector or a large monitor (optional)

For each team of 4-6 students

- ❑ scratch paper
- ❑ pencil

Getting Ready

1. Copy the key concepts onto large strips of paper with a marker. Have them ready to post during the session onto the classroom concept wall. **[RHP 3.10D]**

2. Find a clear space at least 5 meters (about 17 feet) square for the orrery. It doesn't matter whether the space is located indoors or outdoors, as long as it has a smooth surface that can be marked with tape or chalk. **[RHP 3.10E]**

3. Tie knots in the rope corresponding to the orbits of the inner planets. Choose a 2.5 meter piece of rope or string that is not too stretchy, since that will make it difficult to measure the distances of the planetary orbits accurately. Tie a large knot at one end of the rope- this will indicate the starting point of the model, the Sun. Measuring from this first knot out, tie four more knots at the following distances along the rope for each planet's orbit: 58 centimeters (Mercury), 108 centimeters (Venus), 150 centimeters (Earth) and 228 centimeters (Mars). **[RHP 3.10F]**

4. Find several rolls of masking tape or blue painter's tape. The tape will be used to mark out the orbits of the planets. Choose tape that is at least an inch wide, and in a color that contrasts with the color of the surface that the class will be working on. If the model will be staged outdoors on a paved surface, chalk is an easy and convenient alternative to tape.

5. Recruit additional people for the activity if necessary. Setting up the orrery itself is an extensive and integral part of this session and requires the participation of at least 26 students. If you don't have that many students, try to find additional people such as other faculty members, teacher's aides, or students to help your class with this activity. **[RHP 3.10G]**

6. Decide how you will divide the class into teams of 4-6 students for the *Reflecting on Planetary Motion* discussion.

7. If you are planning on showing the CD-ROM orrery animation, set up a computer with a large screen monitor or LCD projector.

GO! Setting Up and Running the Orrery [RHP 3.10H & RHP 3.10I]

1. Remind students of the scale models from Sessions 3.8 and 3.9. Ask students to think back to the outdoor scale model of the inner planets and the mapped scale model of the outer planets. Have students describe their impressions of the scale of distances in the Solar System. [Uncrowded, mostly space, pretty empty.] Point out that these scale models allowed the class to visualize the vast distances between the planets of the Solar System.

2. Tell students that today they will construct another scale model to observe more closely the movements of the planets. Remind students that at the end of the last session, they observed the swirling cloud model and saw how an ordered system could be formed from a disordered one. Tell them that today they will observe another moving model of the Solar System, called an orrery. This model will allow them to look more closely at the movements of the planets around the Sun.

3. The scale of the orrery. Today's model will be *one-hundred billionth* the size of the actual Solar System. Remind students that the outdoor scale model was one-billionth the size of the Solar System, so this model is one-hundredth the size of that model.

4. This sizes of the planets will not be to scale in this model. Emphasize that while the sizes of the planets' orbits *will be* to scale, the sizes of the planets and the Sun *will not* be to scale. Explain to the class that the focus of today's model is on the movement of the planets and not the sizes of the planets themselves, so scaled sizes are not as important.

5. They will all play important roles in the orrery. Tell the class that today's activity is called the ***Human-Powered Orrery***, which means that everyone will be an integral and important part of the moving model!

Modeling Mercury's Movement

1. Move the class to the space you have chosen for the orrery. Bring the knotted rope and tape (or chalk) with you.

2. Have the students stand in a circle. In the center of the circle, mark an X with the masking tape or chalk. Tell the class that the X represents the position of the Sun. Select a student to be the Sun and have him or her stand on the X in the middle of the circle. Remind the class that in this model, the sizes of the objects are not to scale. Tell the students that if the Sun were to scale, it would be less than 15 millimeters (13.9 millimeters) across in this model. [RHP 3.10J]

3. Select 6 students to help form the orbit of Mercury. Assure the class that everyone will have the chance to participate in the model at some point. Give each Mercury student a short piece of tape (about 4 inches long) or a piece of chalk and have them form a circle around the Sun.

4. Explain to the class how each planet's orbit will be set. Tell the class that since today's scale model is only one-hundredth the size of the previous scale model, the distances of the planets today from the Sun will also be one-hundredth the distances that they were in the other scale model. Show the class the length of knotted rope and tell them that each of the knots on the rope represents the scaled distance of a planet from the Sun. The rope will be used to set the orbits of the four inner planets.

5. Set the size of the orbit of Mercury. Have the Sun student hold onto the knot at the end of the rope. Hold onto the first knot (tied 58 centimeters from the Sun's knot) and walk in a circle around the Sun, making sure to pull the string taut as you delineate Mercury's orbit. (The Sun student should turn with you as you walk around.) Ask the 6 Mercury students to space themselves evenly around the Sun along the orbit's path. Once all 6 students are in place, have them each mark their position with their piece of tape or chalk, and then have them rejoin the larger class circle. **[RHP 3.10K]**

6. Choose a student to represent Mercury. Have him or her stand on one of the tape or chalk marks along Mercury's orbit. Ask the class how Mercury moves around the Sun. [It spins while orbiting the Sun.] Tell students that even though the planets do spin around an axis, they will not be modeling this today. Instead, today's model will focus on just the orbital movements of the planets. **[RHP 3.10L]**

7. Modeling Mercury's orbital movement. Tell the class that just as the model has a distance scale, it also has a time scale. The time represented between each tape mark is about 2 Earth weeks. Have the Mercury student step from tape mark to tape mark around the Sun in a counterclockwise orbit. Ask the class how many weeks it would take Mercury to make a full orbit around the Sun using this time scale. [12 Earth weeks.] Ask the Sun and Mercury students to rejoin the larger class circle.

Comparing the Movements of Mercury and Venus

1. Select 16 students to help form the orbit of Venus. Choose another student to represent the Sun. Give each Venus student a short piece of tape or a piece of chalk and have them form a circle around the Sun that is larger than Mercury's orbit.

2. Set the size of the orbit of Venus. Again, have the Sun student hold onto the knot at the end of the rope. Hold onto the second knot (tied 108 centimeters from the Sun's knot) and walk in a circle around the Sun, making sure to pull the string taut as you delineate Venus' orbit. (The Sun student should turn with you as you walk around.) Ask the 16 Venus students to space themselves evenly around the Sun along the orbit's path. Once all 16 students are in place, have them each mark their position with their piece of tape or chalk, and then have them rejoin the larger class circle.

3. Students compare Mercury's tape marks to Venus' tape marks. Have students describe how the tape marks are spaced. [Venus' tape marks are closer together than Mercury's tape marks.] Ask the class how much time is represented between each tape mark. [2 Earth weeks.]

4. Run the model with Mercury and Venus. Choose two students to represent Mercury and Venus. Explain that both planets must move around the Sun according to the same time scale. To help the two planets synchronize their movements, the class will clap and announce "two weeks". **[RHP 3.10M]** With each clap, Mercury and Venus should move along their orbits from one tape mark to the next, counterclockwise around the Sun. Start off slowly at first, clapping about once every 2 seconds. Pick up the pace after a couple of claps.

5. Comparing Mercury and Venus. After a dozen or so claps, stop the class and ask, "If Mercury and Venus were racing around the Sun, who do you think would win the race?" [Mercury.] Have the Sun, Mercury and Venus all rejoin the larger class circle.

Setting the Orbits of Earth and Mars

1. Select 26 students to help form the orbit of Earth. Choose another student to represent the Sun. Give each Earth student a short piece of tape or a piece of chalk and have them form a circle around the Sun that is larger than Venus' orbit.

2. Set the size of the orbit of Earth. Again, have the Sun student hold onto the knot at the end of the rope. Hold onto the third knot (tied 150 centimeters from the Sun's knot) and walk in a circle around the Sun, making sure to pull the string taut as you delineate Earth's orbit. (The Sun student should turn with you as you walk around.) Ask the 26 Earth students to space themselves evenly around the Sun along the orbit's path. Once all 26 students are in place, have them each mark their position with their piece of tape or chalk, and then have them rejoin the larger class circle.

3. Have students compare the orbits of Mercury, Venus and Earth. Students should note that the tape marks in Earth's orbit are closer together than the tape marks in Venus' orbit. Ask students whether Earth will move slower or faster than Venus. [Slower.] Ask students to predict whether Mars will move faster or slower than Earth.

4. Select 25 students to help form the orbit of Mars. Give each Mars student *two* pieces of tape or a piece of chalk. Just as before, have the Sun hold onto the knot at the end of the rope while you walk out a 228 centimeter orbit around the Sun. Ask the 25 Mars students to space themselves evenly around the Sun along the orbit's path. Once all 25 students are in place, have them each mark their position with tape or chalk. Then they should each shift half a space to their right and mark another position halfway between the marks on either side. **[RHP 3.10N]**

Running the Model of the Inner Solar System

1. Select students to represent Mercury, Venus, Earth and Mars. Have the students representing the four inner planets all step to a marked position in their orbit on the same side of the Sun. (The planets should be lined up, as if they are about to begin a race.) Emphasize to the class that this is an unusual planetary alignment. Have students make predictions about the rates of movement of the four inner planets. Ask, "If the planets were racing to complete their orbits around the Sun, which planet would you want to be if you wanted to win this race?" [Mercury.]

2. Run the model. Have everyone begin clapping together. Lead the class in chanting "two weeks" with each clap. Stop the class after 26 claps. Point out that Earth has made one full orbit around the Sun. Ask the class how many weeks have passed. [52 weeks, or 1 year.] Have students describe the progress of the other planets and how much time has gone by for them.

3. If time allows, continue running the model with different students. Try to make sure that everyone in the class gets a chance to participate in the orrery. Solicit comments and observations from students as they observe the model in action. Return to the classroom 10-15 minutes before the period ends. **[RHP 3.10O]**

Reflecting on Planetary Motion

1. Divide students into teams of 4-6. Give each team a pencil and a piece of scratch paper. Ask them to list any true statements they can make after observing the movements of the planets in the orrery. After a few minutes, call on each team to read out one of its statements.

2. Different planets require different amounts of time to complete one orbit around the Sun. Ask teams to discuss whether it is the length of the planet's orbit, or the speed at which the planet moves, which makes the difference in the time it takes to make a full orbit. [Both the speed of the planet and the length of its orbit contribute.]

3. Considering the *year lengths* of the inner planets. Ask students what the term *year length* might mean. [A year is defined as the amount of time it takes for a planet to complete its orbit around the Sun.] Ask students to think back to the orrery and the year lengths of the four inner planets. Ask, "Which planet has the shortest year length? Which planet has the longest year length?" [Mercury has the shortest. Mars has the longest.]

4. Looking at the outer planets. Display the overhead transparency from Session 3.9 that shows the mapped orbits of the outer planets. Ask the class why the orrery included only the orbits of the inner planets. [The orbits of the outer planets are spread out even more than those of the inner planets. Even scaled down to one-hundred billionth of their real size, the orbits of the outer planets would not fit within the school.]

5. Discussing the *year lengths* of the outer planets. Ask students what they might predict about the year lengths of the outer planets [Very long- longer than the year lengths of the inner planets.] Read off the year lengths of the planets to the class:

Mercury's year = 12 Earth weeks or 0.2 Earth years
Venus' year = 32 Earth weeks or 0.6 Earth years
Mars' year = 2 Earth years
Jupiter's year = 12 Earth years
Saturn's year = 29 Earth years
Uranus' year = 84 Earth years
Neptune's year = 165 Earth years

6. Optional: Show the class the orrery animation "ENTER ACTIVITY NAME" on the Space Science Sequence CD-ROM. [RHP 3.10P]

7. A pattern to the year lengths. Ask students if they notice a pattern or trend between the location of the planets and their year lengths. [The farther away from the Sun a planet is, the longer its year length.] Ask students why they think that planets closer to the Sun have smaller year lengths. [These planets have smaller orbits and they move more quickly than the planets farther out from the Sun.] Post on the concept wall:

Planets closer to the Sun have smaller orbits and move more quickly than planets farther from the Sun.

8. Viewing the movements of the planets from the Sun. Ask the class how the movements of the planets would appear to someone standing in the position of the Sun. [The planets would appear to move in an organized and orderly manner around the Sun. The viewer would see a consistent pattern in the motion of the planets.] Post on the concept wall:

Objects in the Solar System are in regular and predictable motion.

9. Viewing the movements of the planets from the Earth. Now ask the class to visualize how the movements of the planets might appear to someone standing in the position of the Earth. [Since Earth is not in the center of the Solar System and is also constantly moving itself, the movements of the planets would seem complex to an observer on Earth. The planets would appear to wander about in different directions.] Tell the class that the word planet comes from an ancient Greek word that means "wanderer." Post on the concept wall:

As seen from Earth, the positions of the planets and the Sun are always changing.

10. Conclude by having teams list the accuracies and inaccuracies of the orrery.

Some things the model showed accurately:

- *All of the planets orbited the Sun in the same direction.* ***(Use this opportunity to remind the class of the swirling cloud model from Session 3.9.)***

- *All of the planets' orbits were in the same plane.*

- *The orbits were all close to circular.*

- *The inner planets moved faster and had shorter orbits than the outer planets.*

Some things the model showed inaccurately:

- *The sizes of the planets were not to scale.*

- *The planets did not spin.* **[RHP 3.10Q]**